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Statement of Sulfates Research Approach

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STATEMENT OF

SULFATES RESEARCH APPROACH

OFFICE OF RESEARCH AND DEVELOPMENT
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D.C.

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16. ABSTRACT

This document presents a strategy to investigate the sulfate question. It defines the approach to be taken, lists the questions to be addressed, provides estimates of resources needed, and time tables to accomplish these goals. It is intended to serve as a long-term planning instrument.

The strategy statement is divided into four research areas: Health Effects. Ecological Effects, Atmospheric Chemistry and Transport, and Measurement Methodology and Instrumentation.

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DISCLAIMER

This report has been reviewed by the Office of Research and Development, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

1. INTRODUCTION

The Environmental Protection Agency (EPA) has long been concerned about atmospheric suspended sulfates. The recent energy-related program to convert power plants from oil or gas to coal, which will increase SO_2 emissions, has heightened our interest in sulfates.

The Office of Research and Development (ORD), the research arm of EPA, has developed a strategy to investigate the sulfate question in a way which would limit the research to manageable bounds. This document defines the approach to be taken, lists the questions to be addressed, provides estimates of resources needed, and time tables for accomplishing these goals.

Hence, the document presents a statement of an *approach* to sulfate research. It is a long-term planning instrument to be considered by EPA program managers, Office of Management and Budget, research managers in other agencies, Congress, and the public. It is intended as a tentative plan, and as such is subject to change and revision both in content and time frames. It does not attempt to present all the technical details of the proposed research, nor does it provide reference documentation.*

This strategy statement is logically divided into four research areas: Health Effects, Ecological Effects, Atmospheric Chemistry and Transport, and Measurement Methodology and Instrumentation. The research program that is to follow from this statement of approach will be an integrated compendium of these four research areas and is to produce scientific evidence to:

1. Provide the scientific basis needed to determine whether regulatory action pertaining to total or selected atmospheric sulfates is warranted.
2. If regulatory action is warranted, provide reasonable scientific bases for setting standards.
3. Define implementable control strategies.

1.1 SCOPE OF THE RESEARCH STRATEGY

As there are too many sulfate compounds in the atmosphere to study each singly and in combination, EPA/ORD will focus its research in the next few years on those compounds and particle sizes likeliest to be biologically significant and which are most commonly found. Prominent among these compounds are sulfuric acid, ammonium bisulfate, ammonium sulfate, and two ionic species: vanadium and manganese. The traditional water soluble sulfate measurement and the measurement of acid versus neutral sulfate relative concentrations will also be evaluated to determine whether they provide adequate indices.

This research program deals only with atmospheric sulfur species, but it is important to recognize that the sulfates problem is actually an integral part of the larger problem of atmospheric suspended aerosols. That is, sulfates are a major component of atmospheric fine particulates, representing 40-60% of RSP in most areas, and in a phased strategy to control fine particulates, the control of sulfates would constitute the most important first step. Sulfates also may be only one of the agents responsible for acid precipitation. However, in order to realistically cope with these larger problems, each component of the problem must be examined.

Although the major contribution to sulfates in the atmosphere comes from stationary sources, some research on emissions from mobile sources is relevant to the sulfates problem. The mobile source research included in this strategy document plan is only that research specifically directed toward determining the health effects of sulfuric acid or specific sulfates generated to simulate expected emissions from mobile sources.

*Even though scientific statements made in this document are unreferenced, they are primarily based upon the references listed in Appendix 1.

Control technology has been developed and is commercially available for controlling significant quantities of potential sulfate precursors such as SO_2 and particulates. Up to 90% of SO_2 emissions from large stationary sources - principally electric generating utilities - can be removed by currently available flue gas desulfurization (FGD) processes. Many major emission sources have already been equipped with FGD processes and are using this technology, and many others are planning to do so. Similarly, particulate emissions can be reduced significantly with available technology. Removal efficiencies in excess of 99% are often achievable at reasonable cost.

Other technology is under development that will reduce total SO_2 emissions, especially in future years. In addition, technology is being evaluated for smaller sources including smaller boilers and industrial processes. EPA and ERDA are developing techniques for the removal of sulfur from fuel prior to combustion. Technologies under development address methods such as physical and chemical coal cleaning, liquified coal, and clean synthetic fuels.

These technologies are under various stages of development, but in future years will minimize emissions of sulfur oxides and other pollutants from increased energy production. The current technology and the results of our ongoing research program could be extended to achieve increased SO_2 control should such a need be identified and mandated. Therefore, it is considered appropriate to leave SO_2 control technology development in the base program, rather than initiate at this time a control technology program directed specifically toward sulfates.

1.2 BACKGROUND

The data regarding causal relationships, biological mechanism, and dose-response relationships of sulfates are extremely limited, particularly at concentrations to which the general population is normally exposed. Epidemiological studies* have tended to show a statistical correlation between measured atmospheric sulfates and the frequency of asthmatic attacks and acute and chronic respiratory disease; however, the quantitative results of these studies are confounded by a wide range of variables and uncertainties. Because of the limitations in available measurement methodology at the time these studies were done, the studies do not distinguish between H_2SO_4 and other sulfates, either acid or neutral. There are other environmental factors, such as temperature stress, as well as other gaseous and particulate pollutants, which are associated with the frequency of these illnesses.

The total sulfur in the atmosphere is probably distributed in a wide variety of gaseous and particulate inorganic and organic compounds or complexes—the number may certainly be many hundreds. The traditional definition of sulfates has been an operational one: material collected on a high-volume sampler filter and analyzed as water soluble sulfates. This method does not distinguish between the various sulfate or sulfite compounds that may be present, nor does it distinguish between the particle sizes. Thus the chemical composition of the sulfate aerosol has not been characterized. Such characterization is important because chemical structure, acidity and particle size of sulfates appear to be important factors related to biological activities, that is the potential for producing adverse effects on humans or other living organisms.

Generally, suspended sulfates are submicron secondary aerosols derived principally from atmospheric reactions of gaseous precursors. However, the observed sulfate concentrations, and in particular the acid sulfates, are not always highly correlated with SO_2 concentrations. The occurrence of acid sulfates does not appear to be linked closely with high SO_2concentrations at a given location. This suggests that factors other than local SO_2 concentrations, such as long-range transport and transformation of primary SO_2 emissions, control the local level of sulfate concentrations. The acidity varies continuously over a wide range, both day and night, within a 3-hour period in a given urban area. Meteorological factors, such as

*U.S. Environmental Protection Agency, *Health Consequences of Sulfur Oxides: A Report from CHESS 1970-1971*, Research Triangle Park, N. C., National Environmental Research Center of U.S. Environmental Protection Agency, May 1974, EPA# 650/1-74-004.

wind direction, indicative of the initial properties of the incoming air mass, are important. The extent of atmospheric transformation and transport are critical relative to an understanding of population exposure patterns and the development of control strategies.

Because of the critical lack of information in the many areas discussed above, the Office of Research and Development (ORD) has in the past few years concentrated on:

1. Identifying through toxicological studies which components/compounds and what size particles in the complex labeled sulfates are biologically active;
2. Developing instrumentation and measurement methodology specifically to identify and analyze sulfur-containing particulate species; and
3. Developing the scientific data needed to relate sulfur oxide emissions to ambient air concentrations of sulfates.

1.3 DISCUSSION OF RESEARCH APPROACH

Long-range planning is essential to assure that resources are best used during the needed long-term sulfate research.

Such planning requires a careful examination of the research strategy so as to maximize the effectiveness of the actual research. There are four general research questions that warrant specific attention.

1. To determine over a broad area the actual chemical composition of atmosphere's sulfates and other sulfur-containing materials. This must include areas dominated by single SO_2 emitting industries, areas dominated by single sulfate emitting industries, and areas with no heavy SO_2 or sulfate emitting industries. This is essentially a definition of the situation as it exists.
2. To provide information concerning the physical characteristics of the sulfates as well as the relationships between the difficult to measure sulfate concentrations and the more easily measured TSP or RSP.
3. Concurrent with 1 and 2, animal studies and human clinical studies where possible must be undertaken to determine the adverse health effects resulting from exposure to those sulfate compounds found to occur most abundantly in the ambient air (individually or in combination).
4. Conduct epidemiology studies to provide field verification of the laboratory studies by utilizing the air pollution indices obtained with the kinds of field monitoring instruments that can be used on control programs. To be useful these studies must demonstrate the most useful index of pollution even though the adverse health effects may be caused by a specific compound, the level of which is reflected fairly consistently, by the level of more easily measured materials.

The research strategy presented in this document is an interrelated series of scientific studies designed to accomplish the Agency's research goals.

Table 1 summarizes the resources that are to be required in completing this research, by projecting funding estimates in the four areas of research: Health Effects, Ecological Effects, Atmospheric Chemistry and Transport, and Instrumentation and Measurement Methodology.

Table 1

SULFATES RESEARCH STRATEGY FUNDING ESTIMATES ($M)

	FY 77	78	79	80	81	82	83
Health Effects	5.4	4.6	7.5	7.5	6.8	6.8	3.5
Ecological Effects	0.9	0.4	1.4	1.4	1.4	1.4	2.0
Atmospheric Chemistry and Transport	4.5	4.5	5.2	5.5	5.3	5.0	2.4
Instrumentation and Measurement Methodology	1.3	1.3	2.3	2.0	1.6	1.3	0.8
TOTALS	12.1	10.8	16.4	16.4	15.1	14.5	8.7

Some priorities are implicit in any funding statement. However, the interrelated nature of the research areas make it very difficult to assign relative or absolute priorities in this research strategy. Figure 1 shows this important interrelationship of the various components of the plan in how the objectives of the research strategy are met.

To decide whether sulfates require regulatory action, the most critical question is whether sulfates cause adverse health or welfare effects at levels found in the ambient air. Such health and welfare data is obviously crucial. No less important, however, are the Measurement Methodology and Instrumentation, and the Atmospheric Chemistry and Transport research, as they provide the ability to characterize the "dose" to the health and welfare effects research. These areas are also important in the initial phases of research to indicate which materials might represent the greater hazards. At the same time, the Atmospheric Chemistry and Transport research must proceed toward developing relationships between ambient levels of sulfates and emissions of their precursors. This information will be required to develop control strategies if sulfates warrant regulatory action.

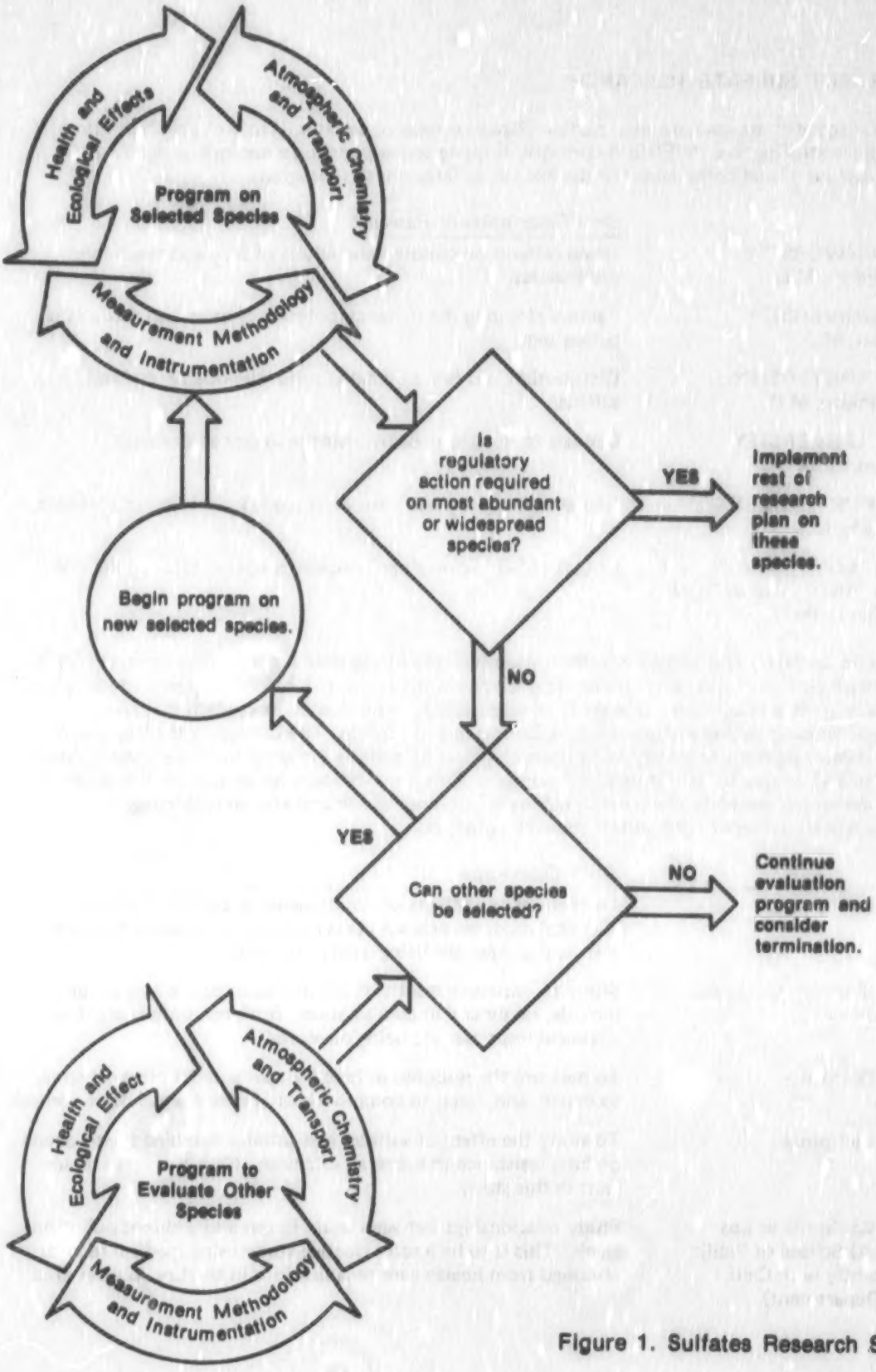

Health and Ecological Effects
Atmospheric Chemistry and Transport
Program on Selected Species
Measurement Methodology and Instrumentation
Is regulatory action required on most abundant or widespread species?
YES
Implement rest of research plan on these species.
NO
Begin program on new selected species.
YES
Can other species be selected?
NO
Continue evaluation program and consider termination.
Health and Ecological Effect
Atmospheric Chemistry and Transport
Program to Evaluate Other Species
Measurement Methodology and Instrumentation

Figure 1. Sulfates Research Strategy

1.4 CONCURRENT SULFATE RESEARCH

Other federal agencies are concurrently studying health effects of sulfates. The National Institute of Environmental Health Sciences (NIEHS) is currently funding and supporting a number of significant studies. Following is a brief compilation of the NIEHS sulfates research program:

Researcher(s)	*Brief Description of Research*
HARVARD UNIVERSITY Benjamin G. Ferris, M.D.	Health effects on children and adults of SO_2 and respirable particulates.
HARVARD UNIVERSITY Mary D. Amdur, M.D.	Factors affecting the irritancy potency of gases and aerosols on guinea pigs.
NEW YORK UNIVERSITY Albert F. Gunnison, M.D.	Distribution and fate of inhaled sulfur dioxide or ingested sulfites.
NEW YORK UNIVERSITY Robert Shapiro, Ph.D.	Damage to nucleic acids by bisulfite in rats and rabbits.
JOHNS HOPKINS UNIVERSITY Federick B. Bang, M.D.	Interaction of SO_2 and virus on respiratory mucosa in chickens.
SOUTHWEST FOUNDATION FOR RESEARCH AND EDUCATION John R. Rowlands, Ph.D.	Effects of SO_2 upon alveolar macrophages in rats and baboon.

The Occupational Safety and Health Administration (OSHA) of the Center for Disease Control (CDC), U.S. Public Health Service is also currently funding studies at the University of Washington on respiratory effects of inhaled gases and aerosols. One study deals with SO_2 induction of peroxide formation.

Other current ongoing studies include work in California and Florida. The California Air Resources Board (ARB) is carrying out a relatively small research effort on sulfates designed to concentrate on problems critical to and unique to California's environment. This program includes laboratory studies on sampling and measuring methods, chemical transformations, and human and animal toxicology.

Following is a brief listing of ARB sulfate research activities:

Institution	*Study Description*
University of California Irvine	To examine the effects of simultaneous exposure to photochemical oxidants and sulfate aerosols on respiratory function. Rats and beagles are being used as subjects.
University of Southern California, School of Medicine	Studying exposure results of asthmatics to ozone and sulfur dioxide, singly and in combination. Both respiratory and biochemical responses are being measured.
University of California Santa Barbara	To measure the response of healthy adults under physical stress to ozone, and, later, to combinations of ozone and sulfate aerosol.
University of California Davis	To study the effect of sulfates and sulfates combined with ozone on lung resistance to bacterial infection. Mice and rats are subjects in this study.
University of California at Los Angeles (UCLA) School of Public Health (and jointly with Calif. State Health Department)	Study relationships between acute illness and ambient pollution levels. This is to be a retrospective study using medical records obtained from health care organizations in the Los Angeles area.

University of California Riverside	Study of the transformation of SO_2 to sulfate aerosol. Processes of inherent and those occurring in a photochemically reacting atmosphere containing hydrocarbons and nitrogen oxides.

Also in California, experimental exposures with special attention to SO_2 and ozone are being carried out by Jack Hackney, M.D., of Rancho Los Amigos Hospital in Downey, California. In addition to normal subjects, persons with relatively mild asthma are being exposed to these gases separately and in combination. As indicators of health effects of these pollutants, the Rancho Los Amigos program is recording symptoms and measuring a number of biochemical and physiological parameters, including forced expiratory volume and forced vital capacity, flow/volume curves, and closing volumes.

In Florida, a statewide sulfur oxides group, funded by the state's electric and gas utility companies, has funded a large sulphur oxides study to be carried out jointly by the University of Michigan School of Public Health (Point of Contact, I.T.T. Higgins, M.D.) and the University of Florida College of Medicine (P.O.C., Heinz J. Wittig, M.D.). The basic objective of this study is to clarify the issues of air quality and human health in Florida, particularly related to the anticipated industrial growth and the accompanying increased use of high sulphur fuel for power production. This study is expected to be completed during 1977. It includes work on health of adults, aged, children, and people with chronic respiratory disease. It will also include studies on mortality and morbidity, as well as some experimental studies. Study sites will primarily be in the Tampa area.

EPA is currently studying these sulfate research findings and is considering recommending an interagency sulfate working group to coordinate sulfur compound research in government agencies. Such a group would improve communication among researchers and protect the interest of both energy and environmental groups.

2. RESEARCH STRATEGY

This document lays out a strategy in developing and measuring the actual conduct of research. As explained in the Introduction, this document is a planning tool to be used in managing and guiding the more detailed plans as the research program is implemented. Specific details including detailed protocols will be worked out, pending management decision on the scope and strategy laid out here and actual resources budgeted during the normal annual budget cycle.

The research strategy that follows is divided into four research areas: Health Effects, Ecological Effects, Atmospheric Chemistry and Transport, and Measurement Methodology and Instrumentation. Welfare effects other than ecological, i.e., visibility reduction and materials damage, are covered under Atmospheric Chemistry and Transport, as is a portion of the acid rain research. Figure 2 is a graphic presentation of the entire research strategy which shows the direction and structure of the research and how the four research areas fit together to meet the program objectives.

Briefly outlined, the research is structured as follows:

1. Monitoring - I
2. Disciplines Involved - II - Toxicology
   III - Epidemiology
   IV - Clinical Studies
3. Effects - Mechanisms, Metabolic Pathways, New Health Parameters (II, III, and IV)
4. Dose Response Relationships - V.
5. Scientific Reports - VI.

The interrelationships of the disciplines involved in the research is illustrated in the figure, which shows the flow of research from defining and identifying those sulfates to be studied to the culminating reports on the health effects of the dose-response relationships. Detailed information and specific methodologies are included in each section of specific areas in this research approach.

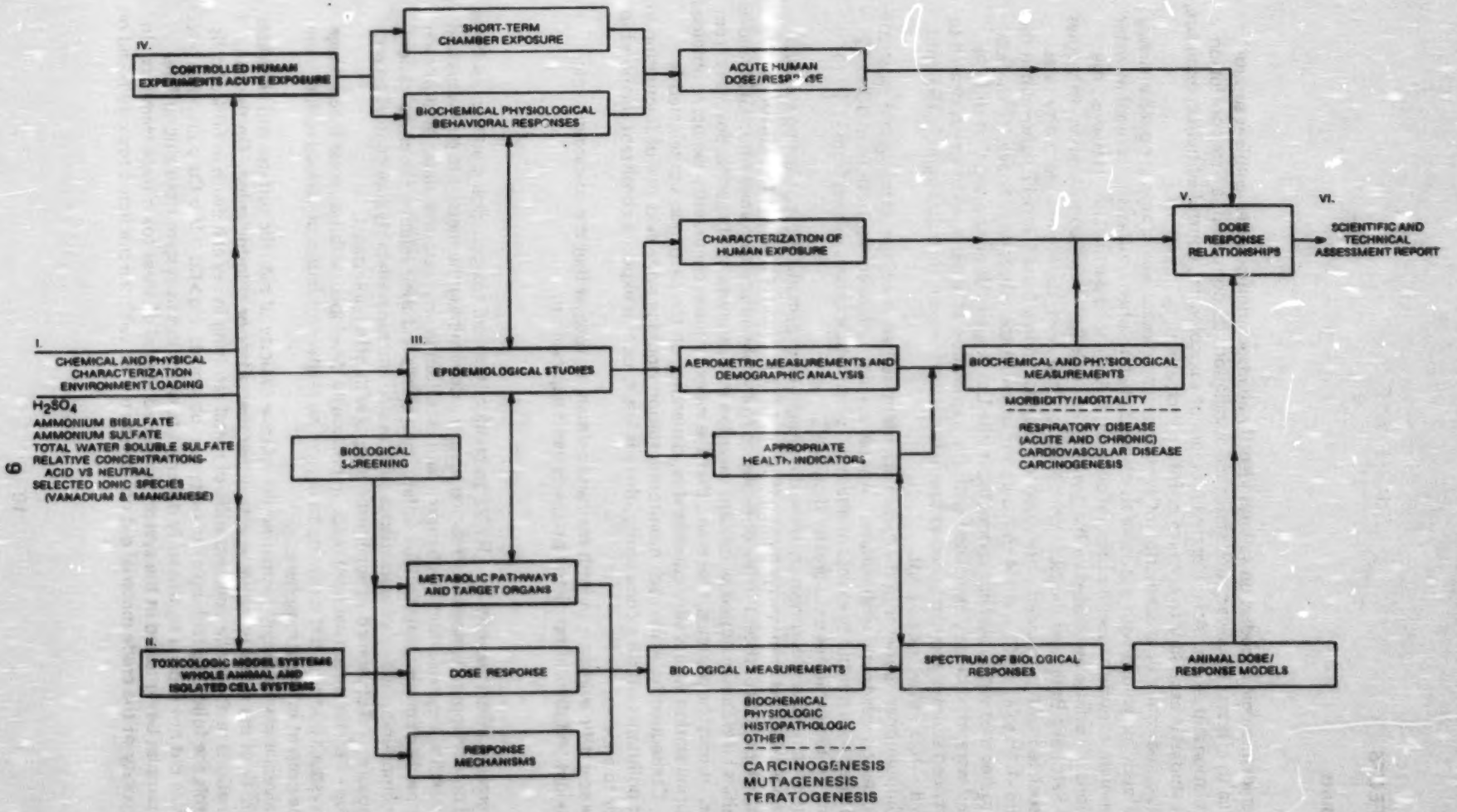


Figure 2. Health Effects Sulfate Research Strategy

2.1 HEALTH EFFECTS

2.1.1 Research Results

EPIDEMIOLOGY–

Results of some epidemiological studies on sulfates identify an association between ambient sulfate levels and adverse health effects. However, such statistical associations do not permit a firm conclusion that a cause-effect relationship exists. An integrated program of toxicological, controlled human exposure, and epidemiological studies is necessary to confirm or refute such a finding.

Study results to date indicate that exacerbation of symptoms and disease which suggest possible airway irritation are more closely associated with exposure to suspended atmospheric sulfates (measured as water soluble sulfates) than with exposure to sulfur dioxide or to total suspended particulate. However, the range of concentrations of sulfates associated with a given health indicator varied considerably. In studies of asthmatics in the Salt Lake Basin and the New York Metropolitan Area, the highest morbidity rates were statistically associated with suspended sulfate concentrations ranging from 12 to 17 $\mu g/m^3$ when the air temperatures were -1.1° to + 10°C, and 1.4 to 7.3 $\mu g/m^3$ when temperatures were above 10°C. Subsequent asthmatic studies (not yet published) conducted in the Los Angeles Basin showed that sulfates levels above 10 $\mu g/m^3$ were most closely associated with the aggravation of asthma, and there appeared to be an interaction between sulfates and ozone, when ozone levels were greater than 300 $\mu g/m^3$ (150 ppb) (Air Quality Standard = 160 $\mu g/m^3$, or 80 ppb).

In a study of cardiopulmonary patients in the New York Metropolitan Area, the strongest and most consistent pollutant association was found with sulfates. Annual average sulfate concentrations of 10 to 12 $\mu g/m^3$ were accompanied by a morbidity excess of about 6% when temperatures ranged from -1.1° to +10°C and 32% when air temperatures were greater than 10°C.

At least some of the inconsistencies shown by these data might be expected. Air monitoring stations have, in the past, been established at locations most convenient for the operator and with little or no regard to criteria for developing a consistent index of exposure from community to community. Grid studies with single communities have demonstrated significant variation in measurement of specific pollutant from one point to another. It must be assumed, therefore, that the index of mean community exposure obtained from a single monitoring station would vary considerably, depending on the particular site selected for locating the station. Consequently, while each monitoring station would provide evidence of fluctuation in the concentration of pollutants within a community, there is less reason to expect a consistent relationship from one community to another.

There is also some scientific evidence, in both man and animals, to suggest that the co-carcinogenic potential of sulfur oxides and their atmospheric products merit exploration.

TOXICOLOGY–

A substantially increased effort was begun in FY'75 to conduct targeted toxicological studies on sulfates. Efforts have focused on developing biological screening systems, determining the metabolic pathways and target organs, understanding responses and mechanisms, and establishing dose-response data. Within each effort, consideration has been given to the various sulfate compounds and their relative toxicities, cation-anion relationships, compound physical characteristics such as size and bioavailability, concentration and time duration of exposure, and combined or synergistic effects with other pollutants.

Biological Screening–Refinements have been made in previously developed rabbit alveolar macrophage systems. These test systems permit rapid screening to determine relative toxicities of various sulfate compounds believed to be present in the atmosphere.

Studies on rabbit alveolar macrophages comparing the relative toxicity of metallic sulfates and chlorides indicate that the toxicity of the metal is the same with either the sulfate or chloride anion. On the basis of quantitative determinations of the molar concentration of metal resulting in net cell death in 50% of cells as compared to controls, the following ranking of toxicity was observed: $Hg > Cd > V > Cu > Zn > Mn \geq Ni$. Zinc ammonium sulfate did not show a significantly different toxicity in this system from zinc sulfate.

Crude particulate samples being tested in the system contained several of these toxic trace elements. In some cases the net toxicity of the crude material did not correlate well with the predicted toxicity based on

the summation of the toxicities of the metals contained within or on the crude sample. For this reason it is important to consider the interactions of toxic trace elements when evaluating the toxicity of environmental samples. Preliminary experiments designed to elucidate and quantitate interactions between toxic trace elements indicate that: (1) copper protects against vanadium cytotoxicity, and (2) selenium protects against cadmium cytotoxicity.

Metabolic Pathways and Target Organs—The target organ for sulfur oxides is the lungs as well as the rest of the respiratory tract. *In Vitro* experiments on normal guinea pig lung fragments exposed to sulfate ions have shown that sulfate ions alone do not induce histamine release. However, ammonium ions may cause histamine release. Studies are now being conducted to determine if immunologically sensitized lung fragments have increased sensitivity to sulfate ions. The effect of H_2SO_4-containing and (NH_4+)- containing sulfate salts on immunologically mediated reactions is also being investigated.

Responses and Mechanisms (Includes dose-response)—These studies indicate that small particle H_2SO_4 aerosol is a greater respiratory irritant than is SO_2, or other particulate sulfur oxides which have been investigated. The irritant effects of H_2SO_4 are aerosol size dependent, i.e., at the same mass concentration small particles which are ± 0.3 μm diameter are more irritating to the respiratory tract than particles ≥ 2.0 μm diameter. The experimental evidence of the irritant effect of H_2SO_4 aerosol at low concentrations (as low as 80 $\mu g/m^3$ at 0.3 μm Mass Mean Diameter (MMD)) is based principally upon the respiratory physiologic response of guinea pigs to short-term exposure to various specific sulfur oxide species. A principal reaction product of H_2SO_4 neutralization, $(NH_4)_2SO_4$, is not a respiratory irritant in the animals that have been studied except at concentrations which are high relative to ambient air levels. Preliminary unpublished data indicate that ammonium bisulfate, an intermediate reaction product of H_2SO_4 neutralization, may have an irritant effect intermediate between H_2SO_4 and $(NH_4)_2SO_4$.

H_2SO_4 inhalation has been found to affect the regional pattern of particle deposition in the respiratory tract of guinea pigs. At a high mass concentration and large particle size (3000 $\mu g/m^3$ and 2.0 μm MMD), a total shift in the regional particle deposition rate occurred. At a low mass concentration and small particle size (30 $\mu g/m^3$ and 0.34 μm MMD) no effect on total respiratory particle deposition was observed, but a proximal shift in the regional deposition of inhaled particles occurred. Recent unpublished evidence indicates that mass concentrations of 160-250 $\mu g/m^3$ of small particulate H_2SO_4 (0.3-0.5 μm MMD) reduces the mucociliary clearance rate of particles from the tracheo-bronchial region of the lung of donkeys, mice, and guinea pigs.

The results of these studies indicate that the site of action of H_2SO_4 aerosol is on the conducting airway epithelium of the respiratory tract. This is the region of the lung in humans most affected by sulfur oxides and which results in coughing, bronchitis and asthma. The conducting airway region seems to be affected despite the fact that the small aerosol size, 0.3-0.5 μm MMD, has a significant potential for deposition in the alveolar region of the lung. This observation, and the fact that H_2SO_4 and other sulfur oxide aerosols are hygroscopic, or deliquescent, suggests that the inhaled particles may increase in size during transit through the respiratory tract and deposit higher in the tract than would be expected based on their initial size. This phenomena, and its implications for health, is the subject of investigations through a variety of experimental approaches. The site of action of H_2SO_4 inhalation demonstrated by experimental studies is supportive of epidemiologic data which indicate that dieases of airways are the principal human responses which have been associated with exposure to sulfur oxide air pollution.

The effect of H_2SO_4, $(NH_4)_2SO_4$, and SO_2 on inhalation respiratory tissues and secretions from a variety of animals has been studied using histophathologic and biochemical methods. Exposure regimens up to 3-4 weeks duration have been used. The results of these studies indicate that inflammatory changes in the lung or conducting airways of the respiratory tract do not develop except at very high mass concentrations relative to ambient air levels (8 mg/m^3 in guinea pigs and higher in other animals). Thus it appears that respiratory physiologic responses to SO_x inhalation occur at concentrations much lower than those that cause direct tissue injury.

The guinea pig appears to be the most sensitive animal to respiratory physiologic effects of SO_x inhalation. The comparative response of normal guinea pigs and humans to SO_2-NaCl aerosol mixtures under high humidity conditions which lead to acid aerosol formation indicates that most normal humans are not adversely affected by 1 ppm SO_2-1 mg/m^3 NaCl whereas this aerosol is irritant of guinea pigs at concentrations as low as 0.25 ppm SO_2-0.5 mg/m^3 NaCl. The high sensitivity of the guinea pig to SO_x aerosol suggests that it may be an analog to individuals who are highly sensitive to SO_x inhalation, particularly asthmatics.

The role of H_2SO_4 and $(NH_4)_2SO_4$ as cocarcinogens with Benzo(a)pyrene during long-term exposure is being investigated. These studies have been in progress for about one year and no data are available as yet.

CONTROLLED HUMAN STUDIES–

Clinical studies are just beginning and initial results should be available in late FY'77.

2.1.2 Research Strategy

The studies described have shown several sulfate species occurring in the ambient air are toxic to animals. However, in these studies, sulfate concentrations were well above those in ambient air. Subsequent efforts will attempt to determine the adverse health effects caused by exposures to ambient levels of the most commonly occurring sulfur compounds, e.g., H_2SO_4, ammonium bisulfate, ammonium sulfate, and selected ionic species, singly and in combination with other sulfates and other pollutants. Significant adverse effects will then require the development of human dose-response relationships for specific compounds. With such information, in conjunction with results from the other research areas, it can also be determined whether the water soluble measurement method or the relative concentration of acid versus neutral sulfates accurately reflects the concentration of these materials. It is anticipated that from these data acceptable indices of the specific sulfate compounds found to contribute to adverse health effects may be developed for control programs.

The gathering of this information requires a closely integrated program involving epidemiological, toxicological and controlled human exposure study areas. Figure 2 shows the various components within each study area and how results from each area are integrated to provide the data base necessary to permit conclusions on specific sulfates, human adverse effects and cause-effect relationships. The approach as shown in Figure 2 is to identify the composition and concentrations of sulfur compounds in the atmosphere, test the compounds in toxicological model systems (whole animal and isolated cell systems), conduct controlled human experiments using short-term exposures, and finally to conduct epidemiological studies in realistic ambient exposure conditions. The output from each of these investigative approaches will then be integrated and assessed to arrive ultimately at a rate of human dose-response to atmospheric sulfates.

A critical pathway analysis of Figure 2 suggests that the epidemiologic studies including the characterization of human exposure probably constitute the most critical aspect of the research effort. This is true because the ambient conditions are the responsibility of EPA and these are studied only by epidemiology technique. Each other aspect of the effort supplements and improves the potential for epidemiology, but none, of themselves, can provide a definitive answer to questions about the need for controlling environmental pollution.

Each of these items, plus atmospheric loading is briefly discussed and a summary of the funding for each item is presented in Table 2.

Table 2

HEALTH EFFECTS RESEARCH FUNDING SUMMARY ($K)

	FY					
Research Area	77	78	79	80	81	82
Toxicology	1573	1065	1875	1575	1575	1575
Controlled Human Exposures	1986	2145	2300	2300	2300	2300
Epidemiology	1815	1380	3364	3600	2900	2900
TOTALS	5374	4590	7539	7475	6775	6775

In addition to the principal strategy that concentrates on the few specific sulfates, a low level effort will continue to develop toxicological data on other sulfur oxides, including sulfites, which occur in the atmosphere and which may cause adverse health effects.

The proposed research should be pursued concurrently in various other federal and university laboratories in addition to a concerted effort within EPA. Such efforts, however, must include, for maximizing utility, a constant exchange of information and ideas to insure greatest possible support for the most promising areas of effort and prudent redirection of programs at appropriate times. This type of information exchange also will minimize undesirable duplication or overlapping of effort, provide for a consistency of study design permitting comparability of study results, and assure the widest possible input and peer review of proposed study objectives, methods and results.

CHEMICAL AND PHYSICAL CHARACTERIZATION OF ATMOSPHERIC LOADING–

Because the number of possible sulfate compounds is too large to study, a review was made of the current data base to identify those compounds which are most likely to be found in the ambient atmosphere and are believed to be biologically irritating or toxic. These compounds are sulfuric acid, ammonium bisulfate, and ammonium sulfate. An initial part of the research program will be to confirm this preliminary finding. Efforts will be made to collect aerometric data on these specific compounds especially in places where population exposure data are required for epidemiological studies. Information on total water soluble sulfate, relative concentrations of acid and neutral sulfates, and selected ionic species (e.g., vanadium, manganese) will also be collected.

TOXICOLOGICAL MODEL SYSTEMS–

This overall toxicology program is designed to provide data necessary in the epidemiologic and controlled human studies, as well as data which will contribute to development of dose-response relationships, to:

1. Assess the relative toxicity of H_2SO_4, NH_4HSO_4, and $(NH_4)_2SO_4$ in whole animals; evaluate the toxicity of other ionic species (HSO_3, SO_3=, trace metals) by *in vitro* methods; this information is input to the design of targeted clinical and epidemiologic studies.
2. Determine the mechanism of biologic response to inhalation of these compounds.
3. Evaluate bio-indicators of response to determine whether or not they are suitable for use in epidemiologic studies.
4. Determine the subacute and chronic toxicity of the compounds which cannot be ascertained by direct human experimentation.

During FY'77-'78 the toxicological studies will be oriented specifically toward an evaluation of the comparative toxicity of strong versus weak acid or neutral sulfate aerosols. These comparisons will be made using respiratory physiologic, pathologic, and microbiologic techniques. These specific compounds will include H_2SO_4 and ammonium bisulfate (NH_4HSO_4) as strong acids and $(NH_4)_2SO_4$ as a weakly acid or neutral sulfate. A few studies of a neutral sulfate such as sodium sulfate, which is found predominantly in the large particle fraction of atmospheric aerosols, may also be investigated. A dose-response relationship will be determined on any sulfur oxides which are found to cause an adverse health response at moderate or low levels. These priorities are flexible since it would be desirable to change them if initial studies of ambient air indicate that other compounds or combinations might deserve more attention.

The toxicological testing program will also include an *in vitro* biological screening program to test other sulfate compounds of unknown toxic potential that may be found in ambient air. The relationship of the ionic composition of the compounds to toxicity and possible protective interactions of elements will be determined. The toxic potential of HSO_3^- and SO_3= will be evaluated. A complete evaluation of copper protection against cadmium cytoxicity will be determined.

There is also a need to develop more specific health indicators. The health indicators used in previous epidemiologic studies have been non-specific, i.e., aggravation of asthma, cardiopulmonary symptoms, and upper and lower respiratory disease. These same conditions may be statistically associated with exposure to other specific pollutants. Therefore, in an urban atmosphere consisting of a wide variety of pollutants, it is not possible, using non-specific health indicators, to determine reliably the contribution of specific pollutants—particularly when there may be synergistic effects. Toxicologic studies will be conducted to analyze possible biochemical changes that may be used as specific indicators of sulfur oxide exposure. These specific response indicators will measure injury as well as physiological and biochemical responses which reflect mechanisms by which the human body copes with a given stress.

The exposure regimen will include both short-term and long-term exposures in order to assess both acute and chronic effects in a variety of animal species. Studies involving metabolic pathways and target organs, and responses and mechanisms will be conducted as part of the short and long-term studies. These studies will provide input to assembling dose-response data.

Table 3

TOXICOLOGY FUNDING ($K)

	FY					
	77	78	79	80	81	82
Biological Screening	100	100	112	94	94	94
Metabolic Pathways and Target Organs	123	100	138	116	116	116
Response and Mechanisms	641	330	718	603	603	603
Dose-Response	709	535	907	762	762	762
TOTAL TOXICOLOGY	1573	1065	1875	1575	1575	1575

CONTROLLED HUMAN EXPOSURE STUDIES–

Ethics prohibit the use of human subjects in the complete spectrum of research necessary to accomplish the objectives of this research program. The experiments must be limited to short-term exposure (acute biological responses) to concentrations approximating maximum ambient or occupational exposure conditions. The objective of these studies will be to determine the level of short-term exposure at which biochemical, physiological, and behavioral responses are observed in human subjects. Initial studies will center on healthy subjects exposed to H_2SO_4. Next, healthy subjects will be exposed to ammonium bisulfate and ammonium sulfate. Studies will continue by exposing susceptible groups (i.e., asthmatics). These studies will be concerned with the significance of factors such as particle size, humidity, temperature and synergistic or inhibitory effects of a second compound. They will determine also the significance of time and concentration factors included in total dose measurements. These data will assist with determining which bio-indicators of response are most appropriate for epidemiological studies and will attempt to develop human dose-response data for specific sulfate compounds.

Table 4

CONTROLLED HUMAN EXPOSURE STUDIES FUNDING ($K)

	FY					
	77	78	79	80	81	82
Low concentrations SO_x exposure	292	300	368	338	338	338
Effects of H_2SO_4 on human immunity	175	200	221	202	202	202
Effects of H_2SO_4 on respiratory function	1519	1645	1711	1760	1760	1760
TOTAL HUMAN STUDIES	1986	2145	2300	2300	2300	2300

EPIDEMIOLOGICAL STUDIES–

The principal aspects of the epidemiological studies are the characterization of human exposure patterns and the use of appropriate health indicators to determine whether there are relationships between ambient levels of the various sulfate compounds and adverse health effects. Epidemiologic studies also will be utilized to determine those indices of air pollution that might best be utilized to implement control programs. Studies will be conducted in cities where sulfates are a major contributor to air pollution. Sufficient preliminary monitoring will be conducted to determine appropriate sites for the health surveys, appropriate locations for monitoring stations, and to assess the chemical and physical characterization of the total atmospheric pollution. The various measurements of pollutants will be correlated to determine if TSP, RSP, water soluble sulfates, or any other readily measured component represents an acceptable index for the toxic fractions (i.e., sulfates). The health surveys will utilize the most appropriate indicators of biological response and health now existing or as they are developed. Studies will be designed to determine the statistical relationship between population exposure to specific sulfate compounds and adverse health effects. Tentatively, studies are planned for Los Angeles, Salt Lake City, St. Louis, the Ohio River Valley, and a northeast coast city to observe if variations in the composition of atmospheric sulfates affects human health. Final selection will be made after detailed atmospheric assessment has been completed. The results will be utilized for developing sufficient human dose-response relationships to indicate possible need for and to support regulatory effort.

Table 5

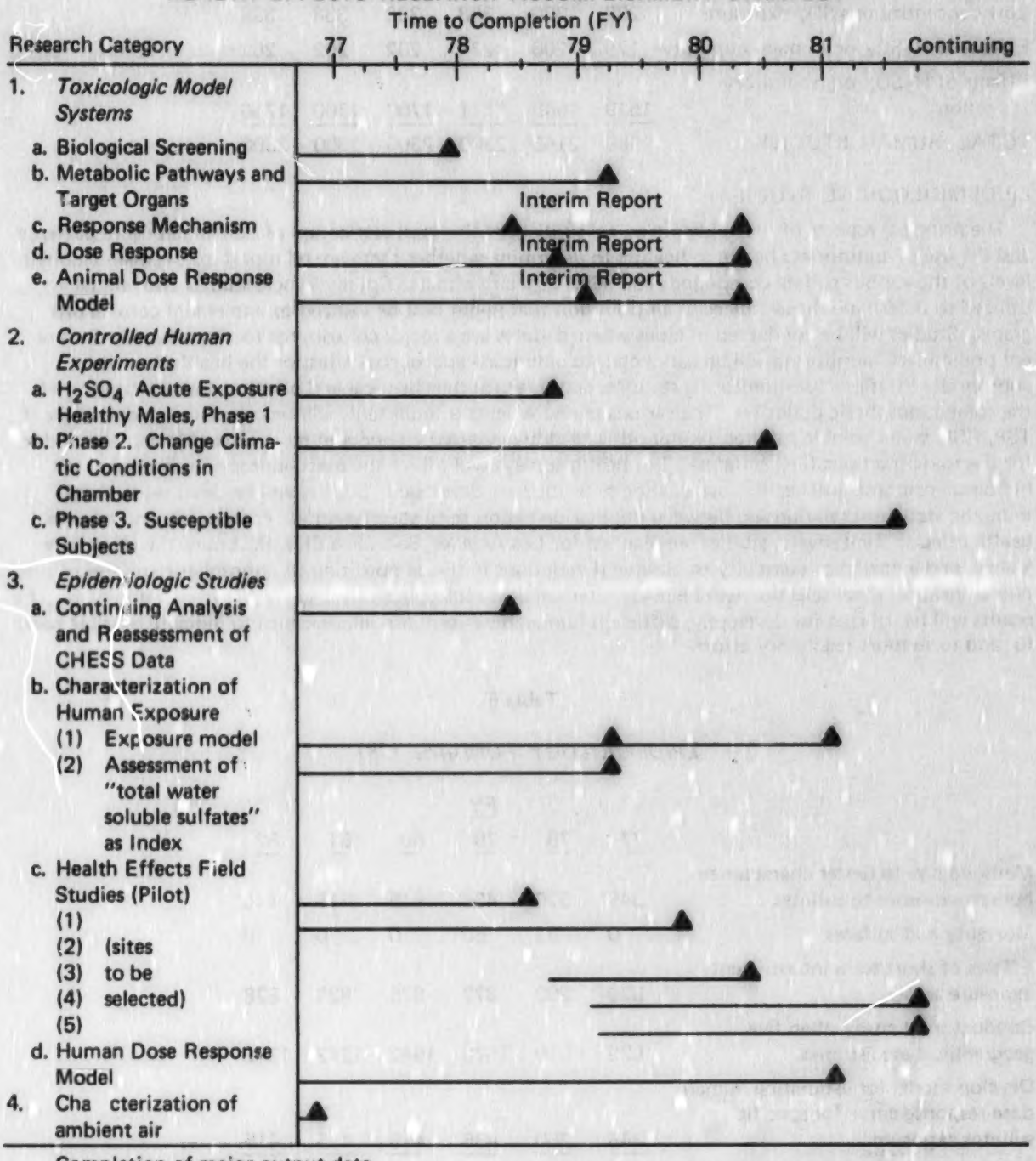
EPIDEMIOLOGY FUNDING ($K)

	FY					
	77	78	79	80	81	82
Methodology to better characterize human exposure to sulfates	345	370	436	415	415	415
Mortality and sulfates	0	50	50	0	0	0
Effects of short term intermittent exposure to SO_x	590	200	872	828	828	828
Conduct pilot study, then five geographical area studies	535	510	1570	1942	1242	1242
Develop model for estimating human dose-response curve for specific sulfates exposure	345	250	436	415	415	415
TOTAL EPIDEMIOLOGY	1815	1380	3364	3600	2900	2900

Table 6 summarizes the research projects and indicates expected completion dates for the major efforts in the Health Effects Research Program. These dates are tentative and are dependent upon correlated research efforts in all areas of the research strategy.

Table 6

HEALTH EFFECTS RESEARCH ACCOMPLISHMENT STRATEGY



Completion of major output date.

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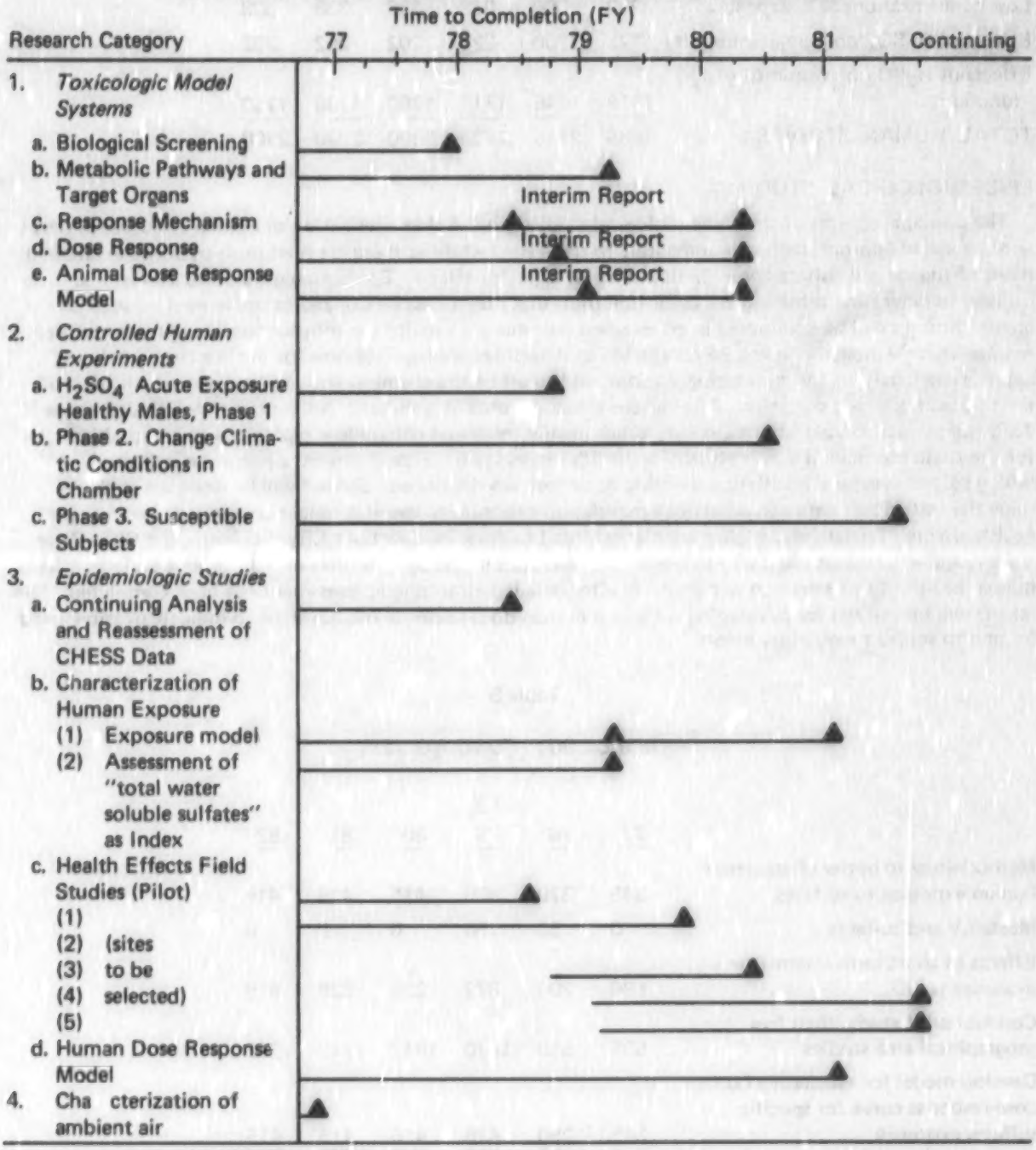


Completion of major output date.

2.2 ECOLOGICAL EFFECTS

2.2.1 Introduction

Sulfur-related welfare effects include ecological damage, materials damage, visibility deterioration, and possible climatological alterations. Of principal concern is the suspected role of sulfur oxides in causing acid precipitation. Existing information does not permit adequate quantification of these effects in order to provide damage estimates. This section, however, deals only with ecological effects. The visibility reduction and materials damage are addressed in the atmospheric chemistry and transport area.

The data elucidating the impact of sulfates on the environment are extensive but largely of recent origin. The information available suggests that changes in the rate of nutrient leaching from plant foliage, acidification of lakes and rivers, and changes in metabolism of organisms, are associated with the increased acidity of precipitation.

Reduction in forest growth in Sweden and northern New England may be correlated with acidic precipitation. Controlled studies indicate that herbaceous plant growth and reproduction are influenced by high acidic precipitation. Pollen germination and pollen tube growth of tomatoes was retarded, resulting in lower production. Timothy grass was also retarded. Studies also show that shifting of soils toward a lower pH causes a shift from the less acid tolerant bacteria to the more tolerant fungi.

Aquatic ecosystems may also be significantly affected by acid precipitation if the input ratios of direct precipitation to land drainage are high. The trend toward increasing acidity in lakes west of Sudbury in Canada and in the lakes and rivers of Scandinavia has been attributed to acid precipitation. Serious fish mortality, particularly of early age classes of salmonids, has been reported in the lakes of both areas.

Studies attempting to determine the specific effects of sulfates on plants are in the early stages. Interpolation, however, may be made from studies dealing with SO_2 effects upon plants, particularly the reactions which occur after SO_2 has entered the leaf through the stomata. Indications are that the SO_2 upon entering the leaf reacts with the water in the air spaces. A major portion of the SO_2 becomes SO_4 ions. These ions then produce chemical reactions within the plant. The exact nature of these reactions is still unknown. The point here is that it may be the sulfate ion which causes the reactions; therefore, similar reactions may be expected from sulfate entering the plant leaf. The majority of these reactions produce detrimental effects within the plant.

The ecological impact of sulfates and acid precipitation are just beginning to become known. Their effects appear to be far-ranging. Increased SO_2 emissions resulting in increased sulfates and increased acid precipitation can only accelerate the changes presently taking place.

2.2.2 Research Strategy

The research strategy consists of two parts: (1) continuation of current research on the direct effects of sulfur oxides, including acid mist on selected crops, forest ecosystems, and terrestrial ecosystems, and (2) an increased effort to study the effects of acid precipitation. A portion of the latter would supplement a Department of Agriculture national acid precipitation monitoring system.

Short term research on acid precipitation could provide the basis for potential welfare standards, by dealing with direct effects on annual and perennial horticultural and agronomic plants. Of course, forest seedlings and more mature trees may suffer direct effects, but because of the long growth period, long-term effort would be needed on forests. Perhaps the most important long-term work will be to determine acid precipitation effects on soils: their chemistry, fertility, and biota. If the soil fertility is damaged, food production would be damaged. Other effects of acid precipitation to be addressed in the long term should be: (1) interactions between plant/animal growth, (2) changes in soil availability of metal to plants and subsequent effects up the food web, and (3) direct and indirect effects of acid rain on aquatic organisms.

Table 7

ECOLOGICAL EFFECTS FUNDING ($K)

	FY					
	77	78	79	80	81	82
Current program on sulfur oxides	860	380	900	900	900	900
Increased program on acid precipitation	0	0	500	500	500	500
TOTAL	860	380*	1400	1400	1400	1400

*For optimal implementation a $980K increase would be required for FY'78.

2.3 ATMOSPHERIC CHEMISTRY AND TRANSPORT

A major objective of the EPA sulfates research strategy is to develop the experimental output and the empirical and deterministic relationship of sulfur oxide emissions to ambient air concentrations of sulfates. Available experimental evidence indicates that almost all of the sulfate species measured on a regional scale (100 to 1000 km) are formed through converting sulfur dioxide to sulfates in the atmosphere during transport of polluted air volumes across regions. Analysis of available aerometric monitoring data and preliminary results on removal rates suggest that elevated point sources rather than low-level point or area sources are the more important contributors to sulfates on a large regional scale (1000km). Within an urban area, particularly during periods of low-level inversions and restricted ventilation, lower level emissions of sulfur dioxide and sulfur trioxide may make substantial contributions to sulfates in high density industrial and commercial areas. The possibility that natural emissions of sulfides contribute to regional sulfate concentrations through atmospheric oxidation to sulfates appears unlikely for many regions, but may contribute to sulfates in certain specific areas. It also has been demonstrated that within the plume from an urban area with high sulfur oxide emissions, high sulfate concentrations can be measured several hundred kilometers downwind under some meteorological conditions. Finally, in the multiday periods during which stagnating anticyclones persist in the northeastern and southeastern U.S., sulfates, along with ozone and other pollutants, can accumulate over large regions in the U.S. Visibility reduction is commonly associated with sulfate formation both in plumes and in stagnating anticyclones.

These physical, chemical and meteorological parameters are important factors to determine the relative contributions of various sulfur oxide emission sources to air quality and also the required control strategies. The experimental results and model predictions must delineate the relative effectiveness of different control options, including usage of low sulfur fuel or reduced industrial activity, and various control technologies on point and area emission sources at urban and non-urban sites. The ability to experimentally follow and to model the effects of such parameters must be on the scale of 200 and perhaps up to 500 km by FY'81.

2.3.1 Workshop on Regional Air Pollution Studies

On June 7-11, 1976, the Environmental Sciences Research Laboratory, RTP, EPA sponsored a workshop on Regional Air Pollution Studies at the Appalachian State University Conference Center in Boone, N. C. The workshop was coordinated by the Triangle Universities Consortium on Air Pollution (TUCAP). Four panels were involved: (a) diffusion and transport (including meso scale meteorology), (b) transformations (including removal processes), (c) measurement and operational strategies, (d) modelling and data management. Members of the panels included university, industry, and government expert scientists including the program managers for the related Electric Power Research Institute (EPRI) and Energy Research Development Administration (ERDA) programs. Several members of the EPA Science Advisory Board Environ-

mental Transport and Movement Advisory Committee participated, as well as EPA scientists from Office of Research and Development laboratories, Headquarters, and Office of Air and Waste Management (OAWM). The main conclusions follow:

(1) The scientific problems discussed are extremely complex and require use of all currently available large scale techniques to measure and trace pollutants.

(2) An adequate scientific program requires combining resources of EPA, ERDA and EPRI.

(3) Experimentation and modelling should be concerned with two different scales. The modelling panel concluded the following:

	Maximum Scale		Resolution		Model Accuracy Goal
Model Type	Distance (Km)	Time	Distance (Km)	Time	(95% Confidence Level)
Plume	500	24 hr	5	15 min	Within a factor of 1.3
Regional	2,000	1 yr	50-100	3 hrs	Within a factor of 2.0

(4) Relationships between single sources and air quality can be derived from plume studies but not in large regional studies.

(5) Transformation can be evaluated in plume studies but not in large regional studies in which steady state conditions with respect to chemical composition and physical changes would be assumed.

(6) Two types of models are recommended: Diagnostic and Planning. Diagnostic models should be used to design and evaluate results of field studies, particularly plume studies. Planning type models are needed to use in developing sulfate control strategies.

Many more detailed recommendations also came from the four panels. The panels emphasized the total national scientific effort needed in sulfate research.

2.3.2 Evaluation of Capabilities of Governmental - Industry Programs

As a result of the Boone workshop (EPA/ERDA/EPRI), project managers evaluated the major and augmenting contributions of their organizations. EPA found major strengths in augmenting and combining efforts to justify future funding on sulfate/nitrate research. A synopsis of such research areas follows:

Atmospheric Monitoring and Characterization	
Surface Network	Augment EPRI effort
Source Characterization-Manmade	Major EPRI effort
Source Characterization-Natural	Major EPA-ORD effort
Physical and Chemical Characterization of Aerosols	Major EPA-ORD effort
Fundamental Research	
Instrument Research	Primary effort by EPA-ORD
Laboratory Kinetics	Primary effort by EPA-ORD
Transport, Transformation, Removal Field Studies	
Point Source Plume	Major effort by EPA-ORD
Urban Area Plume	Primary effort by EPA-ORD
Regional Sub-continental Pollutant Mass Balance	Augment EPRI and ERDA funding
Planetary Boundary Layer	Augment ERDA funding
Surfact Interaction (dry deposition)	Augment ERDA funding

Modelling and Data Management

Numerical modelling-Plume	Primary effort by EPA-ORD
Numerical modelling-Urban Plume	Primary effort by EPA-ORD
Numerical modelling-Large Region subcontinent	Augment ERDA and EPRI funding
Data Management	Major effort by EPA-ORD
Data Analysis	Major effort by EPA-ORD

EPA then would place its research emphasis on characterizing chemical and physical composition of sulfate/nitrate species on a scale so that air quality could be related back to source emission strengths. ERDA, through MAP3S and EPRI, would fund certain plume studies but also emphasize larger scale studies in which sulfate concentration distributions can be related to synoptic weather patterns and climatological factors.

2.3.3 Research Needs

To adequately define these parameters a range of studies are needed on the formation rates, size and chemical composition of product particles and removal mechanisms. These studies include the following types of investigations: (1) laboratory measurements of rates and mechanisms of reaction, (2) simulation of atmospheric conditions in smog chambers or other modelling facilities, (3) an extensive group of field studies, and (4) development of various statistical/empirical models and deterministic or mechanistic models. Both types of models usually require substantial aerometric and meteorological assessment data. Modelling progress is limited by the experimental outputs available on emissions, air quality, meteorological parameters, rates of physical and chemical transformations and removal rates. Adequate sets of experimental outputs also heavily depend on adequate measurement techniques for the gases and aerosol species of concern. Since three-dimensional profiles or fluxes are critical, measurements must be made both at the surface and aloft using techniques with the desired sensitivity, precision and response time.

The primary objective is to determine on a regional scale of 1000 km or more the relative contribution of each class of sulfur oxide emission source to ambient sulfates concentrations within urban areas. Sources requiring investigation include low-level commercial and industrial point sources in urban areas, vehicular emissions particularly in regions of California, high stack emission sources, large area industrial sources, entire urban plumes, natural or biogenic sources, and maritime background in coastal areas.

More specifically, to develop experimental results for modelling the wide range of conditions, measurements must cover individual and complex source plumes under various meteorological conditions: day, night, warm-sunny, cool-overcast, varying humidity, stagnant and well-dispersed air masses, as well as over various terrains.

Of all the biological and non-biological welfare effects, visibility reduction by finely divided aerosol receives great attention by the public and press. In western states installing combustion sources that will deteriorate visibility has been a major concern. Poor visibility is also one of the most aggravating aspects of photochemical air pollution in Southern California.

Because visibility and visual range can be related to aerosol properties by well established physical relationships, there is substantial reason to believe that visibility deterioration caused by sulfates is the most likely welfare effect to be quantitated within the next several years. This could be the basis of a secondary air quality standard.

This position is supported by actual empirical relationships between visual range and the chemical composition of aerosol. This relationship was determined from the Characterization of Aerosols in California (ACHEX) program. This research demonstrated that sulfate species are the most effective scatterers of light, with nitrates being less effective, particularly at low humidities, and other aerosol constituents being poor scatterers. As a result, finely divided sulfate and nitrate compounds contribute more to visibility reduction than their mass concentration alone would indicate. In the eastern U.S., where sulfates dominate on a mass concentration basis, it follows that sulfates must dominate the visibility reduction

problems of eastern regions. Therefore, establishing empirical relationships between visibility and sulfates should be possible with an appropriate experimental program.

Two types of projects should be differentiated in terms of scale of effort. The first type of project is concerned with characterizing sulfate species in specific urban and non-urban locations. One special emphasis would be to differentiate sulfuric acid and other of the more acidic species from the total "water soluble" sulfate and particulate sulfur. The proportion of acid species may vary between urban and non-urban sites, geographic areas of the U.S., seasonal and associated synoptic weather changes, terrain and other parameters. Therefore, representative measurements are needed over sufficient time periods to reflect seasonal and other influences. Another emphasis should be to determine whether natural sources of hydrogen sulfide and mercaptans do contribute significantly other than on a very local scale to sulfate concentrations downwind of swampy areas and of shallow or polluted coastal waters. The resources for such projects are reasonably modest.

The second type of project involves following the large scale movement of sulfur oxides from large elevated stationary sources, extended industrial areas and urban plumes. These projects require tracers, aircraft measurements, remote sensing, upper air meteorological soundings, and other components which result in complex and costly projects. Since the range of environmental conditions of concern are substantial, the number of such projects which can be conducted are limited by total available resources as well as the number of teams of scientific investigators available to participate.

Except in the St. Louis area, no projects currently exist to characterize ground level sulfate species. It must be emphasized, as discussed in measurement methodology and instrumentation, that characterization studies are essential to future planning of biological studies, particularly future population studies. Identifying sulfate species in the atmosphere not currently considered in animal and human laboratory studies will provide new emphasis to such studies. These ground level characterization projects must be integrated into the regional monitoring system of the Electric Power Research Institute (EPRI) at least during intensive periods for the large regional scale research effort (1000 km plus). Similarly, ground level characterization measurements should be made concurrently with plume transport and transformation studies.

Two existing EPA programs provide the field capabilities needed for future studies of the second type. The Regional Air Pollution Program (RAPS) will provide models of the distribution of pollutants in the St. Louis urban area. This program is directed towards a number of criteria pollutants but with particular emphasis on sulfur oxides, including sulfate species. The modelling approach depends on measurements at fixed monitoring sites within and at the outer limits of the metropolitan areas as well as on vertical extensions of these measurements through towers and aircraft. The Midwest Interstate Sulfur Transport and Transformation (MISTT) program has emphasized measurements in the air downwind of St. Louis in the St. Louis plume and following the plumes of the coal-fired power plants and industrial plumes downwind of the St Louis area. Much of the measurement work must be done aloft or by use of remote instruments to obtain the required flux data.

The choice of the St. Louis area for RAPS and MISTT has been productive because of the very large sulfur oxide emissions from power plants and industrial sources in this area. The required additional field work will be completed in FY'76 and FY'77 with one possible winter field project in the MISTT program in FY'78.

2.3.4 Research Strategy

The present RAPS approach will be modified in FY'78 and beyond. In fact, a new acronym, STATE (Sulfur Transport and Transformation in the Environment), has been proposed. The present use of a 12-month-a-year base measurement program with more extensive measurements during certain periods is too demanding of available resources. Future field research in both STATE and MISTT will emphasize intensive periods of field research activity with greater use of mobile ground units and aircraft rather than fixed ground sites. This latter approach is essential to follow trajectories of various plumes over large distances. A fixed regional surface network of the required density will be provided by the EPRI program. Further-

more, the intent in future studies is to cover more field situations using several intensive measurement periods in various regions. This method of field study will require greater flexibility than in the current RAPS program, but should be more cost-effective.

At realistic current and projected (intramural and extramural) resource and manpower levels, a seven-year program is needed to develop the minimal information base to devise and implement a sulfate standard and control strategy. The period would cover the time span from FY'77 through FY'83. This projection assumes only minimal contributions from other U.S. (EPRI, ERDA) or European programs up to 1977 but substantial contributions after that, particularly from the results of large regional scale (1000 km) programs. If the scope and timing of these other programs should become more directly compatible with EPA needs, some reductions in program lengths are possible but not predictable. There is also anticipated support from other sources, such as the National Science Foundation, for laboratory projects to investigate reaction mechanisms and simulation studies.

The needs described above will be addressed by:

I. Laboratory Mechanistic Research and Simulation Studies
II. Chemical Characterization of Acid Sulfates
III. Regional Plume Studies (formation, dispersion, transport, transformation and removal processes) and Regional Sub-continental Studies (Supplement EPRI Measurements at monitoring sites and provide remote sensing capabilities)
IV. Environmental Energy Related Programs
V. Effects on Visibility Reduction
VI. Effects on Materials
VII. Association of Acid Rain Effects with Meteorological Parameters
VIII. Data Analysis and Modelling of Sulfates.

Table 8a

ATMOSPHERIC CHEMISTRY AND TRANSPORT FUNDING FOR SULFATES ($K)

		FY						
		77	78	79	80	81	82	83
I.	Chemical Mechanism and Simulation[a]	400	400	450	450	450	400	200
II.	Chemical Characterization of Acid Sulfates[b]	175	400	600	450	250	200	0
III.	Experimental Regional Plume Studies	2255	1900	1900	2000	2000	1800	0
IV.	Environmental Energy Field Studies	900	900	1050	1075	1075	1050	1100
V.	Visibility Reduction	50	125	200	175	100	50	0
VI.	Materials Effects	20	100	150	150	150	150	0
VII.	Acid Precipitation Association with Meteorological Parameters	50	50	100	150	150	100	100
VIII.	Modelling[c] and Data Analysis	650	625	750	1050	1125	1250	1000
	Environmental Energy Subtotal	1250	1275	1275	1275	1275	1275	1275
	TOTALS[d]	4500	4500	5200	5500	5300	5000	2400

[a]including energy related projects, See Table 9

[b]not including measurement methodology and instrumentation research

[c]including energy related projects, See Table 16

[d]including resources for EPA technical staff involved in projects.

EPA resources included are only those considered directly relevant to understand the formation, dispersion, transport and removal of sulfate and their non-biological effects. Research, whether basic or applied, which is not pollutant specific is not included. For example, laboratory research on the physics of formation of aerosols not specific to sulfates is not included. Research on air pollution modelling, climatology, or removal processes which is possibly applicable to a variety of pollutants but not specific to sulfates also would not be included in the resources. Similarly, research on nitrogen oxides and nitrates are available but not included in this plan. Separate activities covering these topics are provided within the EPA program element structure on atmospheric chemistry and transport. This approach avoids duplicate counting of resources or alternatively making the present plan an air pollution research plan rather than a sulfate research plan. Finally, the resources do not include the substantial contribution made to the EPRI/SURE (Sulfate Regional Experiment) program because of the anticipated loan of a sizeable fraction of the RAMS Stations and equipment from St. Louis to the SURE network.

The research components I through VIII in Table 8a respond to three major objectives: (A) Projects supporting the health and welfare aspects of criteria development and an ambient air standard in

determining what concentrations and compositions of various sulfate species cause responses or effects; (B) Developing needed mathematical relationships between emission rates and air quality to initiate control strategy whatever may be the standards pathway selected; (C) Energy technology related projects investigating the impact of new technologies on the composition of plumes. Table 8b reallocates by year the resources listed in Table 8a.

Table 8b

ATMOSPHERIC CHEMISTRY AND TRANSPORT FUNDING BY OBJECTIVES ($K)

	FY						
	77	78	79	80	81	82	83
Objective A	170	475	600	625	400	300	100
Objective B	3080	2725	3300	3575	3600	3400	1000
Objective C	1250	1300	1300	1300	1300	1300	1300
Totals	4500	4500	5200	5500	5300	5000	2400

I. Chemical Mechanism and Simulation Studies–

These ongoing laboratory programs have the following objectives: (1) provide basic data on mechanisms and processes related to oxidation of gaseous sulfur compounds to aerosols and the associated physical changes in aerosols as they follow and grow; (2) simulate chemicals or physical processes occurring within specific types of plumes to associate processes with effects of precursors, humidity, temperature and catalysts on conversions of sulfur oxides to sulfates.

Table 9

CHEMICAL MECHANISM AND SIMULATION FUNDING ($K)

	FY						
	77	78	79	80	81	82	83
Base	250	250	300	350	350	300	100
Environmental-energy	150	150	150	100(a)	100(a)	100(a)	100(a)
Total	400	400	450	450	450	400	200

(a) assumes continuation of environmental-energy resources through FY82.

II. Chemical Characterization of Acid Sulfates–

Recent laboratory biological results reveal that initiating such characterization studies is essential for selected sulfate species. As a result, a characterization project will be initiated during the first half of FY'77 to measure acid sulfates, total sulfates, and a number of elements by XRF, at sites both of interest for future population studies as well as transport studies. The first group of sites will probably include a site in Los Angeles, Utah, Missouri or Illinois (near St. Louis), and several other midwestern and east coast sites. A small initial intensive project will be carried out on natural emissions in the Cape Hatteras area of coastal North Carolina. The prototype instrumentation to optimize such investigations of natural emissions will not be available until 1977, so only manual and research laboratory measurements can be made until then. These characterizations at urban sites of interest to population studies will continue for several years. Additional intensive measurement projects will be set up at non-urban EPRI/SURE monitoring sites. Such characterization measurements will also accompany transport and transformation studies of larger plumes.

A series of studies to determine whether natural emissions contribute significantly to regional problems will continue through FY'78 to FY'80.

Table 10

CHARACTERIZATION OF ACID SULFATES FUNDING ($K)

		FY					
		77	78	79	80	81	82
1.	Measurements at possible sites for future population studies.	100	200	250	150	0	0
2.	Measurements to supplement EPRI monitoring system for regional studies.	50	100	150	150	100	100
3.	Measurements to supplement intensive regional plume studies[a]	0	200	200	250	250	150
4.	Measurements of natural emissions.	25	100	250	150	150	100
	TOTALS	175	600	850	700	500	350

(a) Resources included in Regional Plume Studies (III)

III. Regional Plume Studies–

In FY 1973 a regional air pollution study (RAPS) was initiated in the St. Louis area by White House initiative. The study was scheduled as a five-year program through FY'77. Funding has been at the 4 to 5 million dollar range per year during this study. The scope of the study was somewhat narrowed with respect to the range of pollutants. Particular emphasis has been given to sulfur dioxide, sulfates and other finely divided particulate species; however, a significant portion of the measurement program also has been directed at obtained data related to ozone and its precursors. An extensive measurement system for gases and particles has been set up in the St. Louis region, including nearby areas, on a scale not exceeding 100 km. A number of successful intensive periods of investigation have been conducted involving additional specialized gas and aerosol measurements at ground level and from aircraft, also including upper air meteorological soundings. A detailed "high resolution" emission inventory has been in development. The final intensive field activities will be carried out in late fall or winter of 1976-77. The monitoring network and meteorological network will be phased down in the second half of FY'77. During FY'76 and FY'77 increased emphasis has been given to data analysis and modelling. However, because of the phasing on availability of emission inventory results and some other aspects, modelling will not be completed in FY'77. Therefore, FY'78 modelling funding discussed below for the second phase of RAPS (STATE) must include transitional funding to complete the utilization of RAPS from St. Louis.

As discussed above, the second phase of regional air pollution research (STATE) involves considerable shift in emphasis. The efforts will concentrate on the contribution of elevated emission sources (stacks) of sulfur oxides and nitrogen oxides to regional concentrations of sulfates and nitrates. Chemical compositional efforts will emphasize acid sulfates and acid nitrates. The scale selected is the 100-500 km range since it is within this range that there is a reasonable possibility of developing relationships between emissions and the ambient air concentrations of total and acid sulfates and nitrates. Because the Electric Power Research Institute (EPRI) is already committed to operating a large regional monitoring network, there is no need for EPA to provide such a network. However, the EPA measurements capability does provide the opportunity to supplement the measurements of the EPRI network by chemical characterization for acid

sulfates and other species which EPRI will not measure in their basic monitoring program. Therefore, the proposed program emphasizes following the movement and chemical and physical characteristics of plumes from large utility complexes and their interactions with urban areas. In the first and possibly second field study, a midwestern complex or one located on the boundary between midwest and southeast U.S. will be selected. A complex is desired which will be so located that both polar and gulf maritime air trajectories will pass over the complex. Among other reasons for this choice is the possibility of large variations in the levels of acid sulfates with changes in frontal passage. Another aspect will be determining the interaction of the plume(s) from the complex with an urban area well downwind of the complex. Later efforts will be directed at impacts on the east coastal areas. It has been suggested that the combined efforts on plumes and on the regional-subcontinental scale be termed STATE (Sulfate Transport and Transformations in the Environment). Because of the programs to be funded by EPRI and ERDA on the regional-subcontinental scale, EPA will emphasize the plume studies. The STATE program will be a five-year program on both sulfates and nitrates. In this strategy only the resources for sulfates are listed.

Resources listed cover the following aspects: (a) detailed chemical characterization in aircraft and at mobile ground sites, (b) use of tracers to follow movement of plumes, (c) use of aircraft measurements and remote sensors to obtain flux of pollutants at a number of downwind distances (times), (d) special meteorological measurements needed aloft, and (e) data analysis.

Table 11

*REGIONAL PLUME STUDIES FUNDING ($K)**

		FY					
		77	78	79	80	81	82
1.	Urban-regional program (10-100 km) RAPS	2190[a]	0	0	0	0	0
2.	Plume intensive field programs (100-500 km)	0	1600	1600	1700	1850	1650
3.	Regional-sub-continental program (1000-2000 km)	65	300	300	300	150	150
	TOTALS	2255	1900	1900	2000	2000	1800

*RAPS and STATE both address pollutants other than sulfates. Shown here is that portion judged to apply to sulfates only.

[a]Not including modelling or methods development

IV. Environmental Energy Major Field Programs–

Two major field programs have been funded by environmental energy resources. One of these programs, MISTT, has been concerned with transport and transformation in plumes from various energy sources. However, the field work thus far in practice has concentrated on coal-fired power plant plumes in the St. Louis area and the urban plume of St. Louis. The scale has been in the 50 to 250 km range with the longer range for the urban plume. Field projects in FY'78 and beyond will study specific types of plumes from single sources. The second program is concerned with obtaining experimental data on a coal fired power plant (Clinch River near Carbo, Va.) plume in complex terrain. A similar study should be conducted at an appropriate western site. The data will be used to improve modelling of plume behavior in complex terrain.

Table 12

MAJOR ENERGY-RELATED FIELD PROJECTS FUNDING ($K)

	FY					
	77	78	79	80	81	82
MISTT project	575	700	850	875[a]	1075[a]	1095[a]
Complex terrain-project	325	200	200	200[a]	0	0
TOTALS	900	900	1050	1075[a]	1075[a]	1095[a]

[a]Assumes energy funding will continue after FY'79

V. Effects of Sulfates on Visibility Reduction–

The dominant role of finely divided sulfates on visibility reduction has been discussed. Concurrent measurements of sulfates and visual range will be made at a number of urban and non-urban sites including some EPRI sites and sites where population studies also will be conducted. Varying visual conditions also will be related to meteorological parameters.

Table 13

VISIBILITY REDUCTION FUNDING ($K)

	FY					
	77	78	79	80	81	82
Visibility Studies	50	125	200	175	100	50

VI. Effects of Acid Sulfates on Materials

EPA has made field measurements to evaluate deterioration of construction materials in St. Louis. However, present and past evaluations have not been designed to separate effects of sulfur dioxide from effects of acid sulfates. The distribution of damage on a regional scale may well be different depending on the contributions of sulfur dioxide compared to acid sulfates in causing damage. Selected paired urban and non-urban sites should be evaluated.

Table 14

MATERIALS DAMAGE FUNDING ($K)

	FY					
	77	78	79	80	81	82
Base	0	100	150	150	150	150
Energy	20	0	0	0	0	0
TOTALS	20	100	150	150	150	150

VII. Association of Acid Precipitation Effects with Meteorological Parameters–

Increased acidity of soil and inland waters has been observed in Sweden, Norway, Canada, and the U.S. The effect has been associated to a large extent with acidity of sulfure particulate matter often transported distances of 1000 to 2000 km and transferred from the air to soil or water bodies by precipitation. The most consistent effect has been on spawning and growth of trout and salmon in lakes and streams. In the

U.S. this effect occurs in high altitude lakes in the Adirondack mountains with extinction or alterations in density, size, structure, and growth rates of trout populations. Evidence has accumulated that one particularly adverse condition is the extremely high acidity of spring snow-pack runoff. However, high levels of acidity also occur during certain types of individual precipitation episodes. An evaluation of these types of conditions will be related to meteorological conditions and emission sources over the eastern North American Continent. The resources for ecological research are included elsewhere in this strategy.

Table 15

ACID PRECIPITATION FUNDING ($K)

	FY						
	77	78	79	80	81	82	83
Acid Precipitation Studies	50	50	100	150	150	100	100

VIII. Data Analysis and Modelling of Sulfates–

Data analysis is needed of RAPS results as well as of the experimental results from the new regional programs (STATE) proposed to develop empirical relationships between emission sources and ambient air sulfates. Evaluation of urban-regional scale models (10-100 km) using St. Louis RAPS experimental results will be emphasized in FY'77 and FY'78. Development of deterministic plume models (100-500 km) and regional subcontinental models should be emphasized in FY'77 and FY'78 to permit evaluation and modification in FY'79 and later. Both diagnostic and planning type models are needed. It should be emphasized that a different set of models are required to deal with the plume and regional-subcontinental scales. The plume models will include modules for chemical and physical changes and will involve much higher spatial and temporal resolution than the regional-subcontinental models. It should again be emphasized that supporting research on model development techniques not of a pollutant specific character also will be in progress but the resources are not included in this strategy.

Table 16

DATA ANALYSIS AND MODELLING FUNDING ($K)

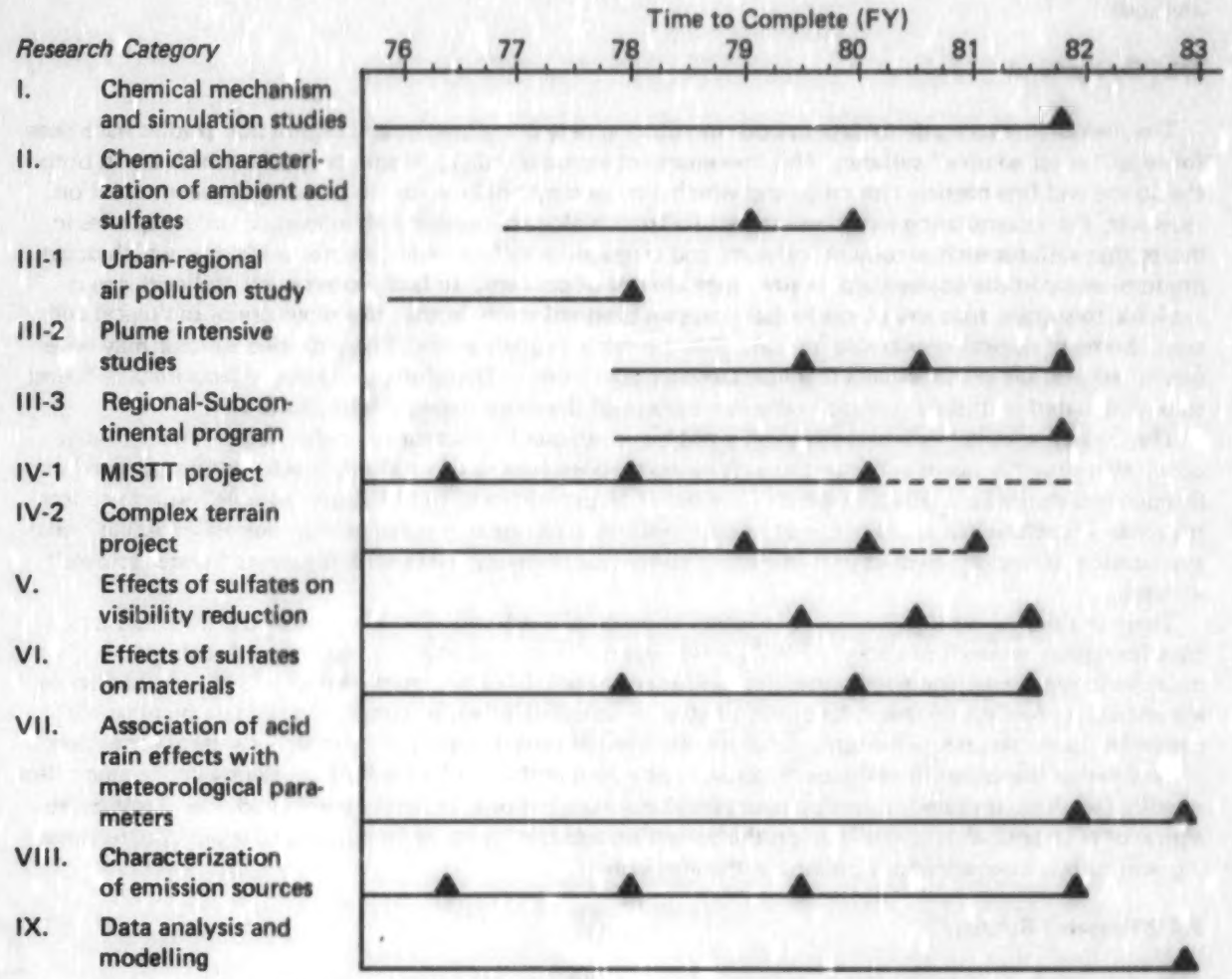
		FY						
		77	78	79	80	81	82	83
1.	Development and evaluation of urban regional plume models	350	325	400	650	700	700	600
2.	Development of regional subcontinental models	100	150	250	300	325	450	300
3.	Environmental	200	150	100	100[b]	100[b]	100[b]	100[b]
	Total resources including those in III	650	625	750	1050	1125	1250	1000

[b]Assumes continuation of environmental energy funding beyond FY'79

Table 17 summarizes the nine research areas and major milestones in each, for the Atmospheric Chemistry and Transport Research Strategy.

Table 17

ATMOSPHERIC CHEMISTRY AND TRANSPORT



The ability to meet the completion dates shown in Table 18 depends as much on the continued availability of key ORD-EPA scientists as on dollar resources. With the continuing reductions in laboratory staff in ORD-EPA, there is no assurance that the key atmospheric scientists needed to manage and implement this portion of the strategy can be replaced if they resign or are transferred. The completion dates listed are based on actual laboratory staffing at the beginning of FY'77. Losses of staff will require that various of the individual completions be shifted to later dates or deleted entirely. This uncertainty as to future staffing also is one reason why it is unrealistic to propose higher levels of dollar resources in these research areas despite the realization that the present EPA strategy is less than optimum.

2.4 MEASUREMENT METHODOLOGY AND INSTRUMENTATION

A critical need in the present research strategy is to develop methods for monitoring specific sulfur compounds in ambient air. Epidemiological, toxicological, clinical, and atmospheric formation studies depend on the availability of such methods. Any effort to understand the relationship between the emission of sulfur compounds and sulfates and ambient air quality also depends upon the adequacy of the measuring methods.

2.4.1 Background

The measurements made to date in both monitoring network activities and population studies have been for total "water soluble" sulfates. This measurement includes individual sulfate species which are in both the coarse and fine particle size range and which may or may not be acidic in nature in aqueous solution. However, the accumulating experimental results from biological studies with individual sulfate species indicate that sulfates such as sodium, calcium, and magnesium sulfate which are not acidic and which occur predominately in the coarse particle size range are not of concern. In fact, no experimental evidence is available to suggest that any of the sulfates present predominantly in that size range are of biological concern. Some biological results also indicate that the more strongly acidic, finely divided sulfates may have greater adverse biological effects than less strongly acidic ones. Therefore, biological effects may be found to be associated with the presence in the atmosphere of the more strongly acidic sulfates.

The "water soluble" sulfate method may not be an adequate indicator of acid sulfates. This tentative conclusion urgently needs verification. It is based on observations of variation in acid sulfate reported in Sweden and in the St. Louis area which were not at all proportional to the "water soluble" sulfate concentrations. Therefore, the completion of related measurement research is essential to permit initiating a characterization project at selected sites in FL'77-'78 to quantitatively relate acid sulfates to "water soluble" sulfates.

There is a similar need to include characterization of acid sulfates as an element of the transport and transformation research projects in FY'78 and beyond. These projects also require the capability to measure total gaseous and total particulate sulfur accurately to obtain mass balances. Such mass balances are critical to develop reliable relationships between emissions of sulfur compounds and ambient sulfur concentrations. Ammonia measurements are also needed to test kinetic mechanism of sulfate formation.

To develop the capabilities discussed above, it is essential that artifact sulfate caused by converting sulfur dioxide to sulfate on some collection substrates be minimized or completely eliminated. Similarly the reaction of ammonia with acid sulfate on the collection substrate must be minimized to avoid underestimating acid sulfate concentrations present in the atmosphere.

2.4.2 Research Strategy

The considerations discussed result in eight project activities discussed below. A summary of funding for each is presented in Table 19.

Discussions with representatives of EPRI and ERDA as well as knowledge of European programs indicate that only limited efforts on sulfate laboratory measurement techniques and little if any instrumentation development can be expected by other sources. The only major instrumentation program is being conducted by EPA. Currently several of the measurement research activities in ERDA laboratories are supported as part of the EPA program. In addition, NSF has funded a number of basic measurement projects with some general relationships to this plan. Therefore, the described research and funding is essential not only for EPA, but for the total national effort on sulfates.

The items included are those specifically related to sulfates and not air pollution or environmental measurements in general. For example, measurement projects to analyze for specific elements usually reflect concern about the specific toxicity of these elements. Unless the element has a reasonable

association with sulfates and current methodology is inadequate to meet the needs in the sulfate strategy, it was considered inappropriate to include such resources as pertinent to sulfates. To include research on even less directly related measurements on organics, oxidants, and nitrogen oxides would turn a sulfates research strategy into a non-specific catch-all environmental research effort.

I. Particle Sizing–

Sulfates must be separated into fine and coarse fractions by use of an appropriate particle sizing device. As discussed, this separation is required because of the lack of biological response to coarse particles. This separation is also useful because it eliminates or reduces the interference of alkaline substances present predominantly in the coarse particle size range with acid sulfate measurements. The collection surfaces in the particle sizing device must be compatible with subsequent analysis for acid sulfates and "water soluble" sulfates.

Table 18a

MEASUREMENT METHODOLOGY AND INSTRUMENTATION FUNDING ($K)

		FY						
		77	78	79	80	81	82	83
I.	Particle sizing	245	175	175	125	100	75	0
II.	Key sulfate species	165	165	310	150	150	150	0
III.	Other sulfate species	30	50	150	150	150	50	0
IV.	Other particle sulfur	25	50	150	175	100	50	0
V.	Inst. for Transf. & Transp. Res.	145	150	250	150	150	125	0
VI.	Natural sources	20	50	50	0	0	0	0
VII.	Develop monitoring techniques	135	125	225	200	200	200	200
VIII.	Source Characterization	135	135	315	300	250	150	150
IX.	Standardization	100	100	375	450	200	150	150
X.	Env. Energy Pass-Thru	300	300	300	300	300	300	300
	TOTALS[a]	1300	1300	2300	2000	1600	1250	800

[a]including resources for EPA technical staff involved in projects.

The research components I through X in Table 18a respond to three major objectives: (A) projects supporting the health and welfare aspects of criteria development and an ambient air standard in determining what concentrations and compositions of various sulfate species cause responses or effects; (B) development of the mathematical relationships between emission rates and air quality needed to initiate control strategy development whatever may be the standards pathway selected; (C) energy technology related projects investigating the impact of new technologies on the composition of plumes. In Table 18b the resources listed in Table 18a are reallocated by year among these objectives.

Table 18b

MEASUREMENT METHODOLOGY AND INSTRUMENTATION
FUNDING BY OBJECTIVE ($K)

	FY						
	77	78	79	80	81	82	83
Objective A	220	265	610	475	400	250	0
Objective B	780	735	1390	1225	900	700	500
Objective C	300	300	300	300	300	300	300
Total	1300	1300	2300	2000	1600	1250	800

II. Key Sulfate Species–

Analytical and instrumental techniques capable of providing for separation and analysis of sulfuric acid, ammonium bisulfate and ammonium sulfate are essential. Techniques which measure compounds directly are desired, but these techniques, which involve estimating of individual compounds by deducting from a set of acid sulfate measurements, are acceptable.

III. Other Sulfate Species–

Efforts will continue to determine whether other sulfate species in the finely divided particulate matter with potential to cause adverse biological effects actually occur in the atmosphere. One such possible species has been identified in the stacks of oil-fired power plants. This species appears to be a compound of vanadium and sulfur, possibly vanadyl sulfate, $VOSO_4$. Special research techniques must be applied to verify this result and to seek other possible species in the atmosphere.

IV. Other Forms of Particulate Sulfur–

Other valence states of particulate sulfur may be of significance. Sulfites especially have been suggested as of possible importance. Therefore, measurement techniques acceptable for air quality research on valence states and molecular compounds of sulfur need to be developed and applied.

V. Instrumentation for Transformation and Transport Research–

For transformation and transport research there is an additional need for real time or semi-real time instrumentation to measure total particulate sulfate, as well as sulfur dioxide and ammonia at the concentration levels of concern in regional scale studies.

VI. Natural Sources–

Natural emissions of hydrogen sulfide and mercaptans are frequently discussed as contributors to ambient sulfate concentrations as a result of oxidation mechanisms. To conduct adequate studies of natural emissions a measurement system must be develop which will be adequate to differentiate among the sulfur species involved in the process of conversion of such reduced sulfur vapors to sulfate.

VII. Monitoring Needs–

There is a need for low cost devices for measurement of sulfur dioxide, sulfuric acid and other acid sulfates. Continuing research is needed to develop devices that will be practicable for routine monitoring.

VIII. Characterization of Emission Sources–

This characterization strategy is primarily concerned with chemical and physical characterization of sulfates from oil-fired stationary sources. Recent experimental results have demonstrated that directly emitted sulfate emissions in the form of sulfuric acid and a vanadium/sulfur species, probably vanadyl sulfate, are larger than indicated by experimental results obtained a number of years ago. The sulfate levels obtained are sufficiently higher to be of possible concern if unstable meteorological conditions exist immediately downwind of the source (1-10 km). Additional evaluations are needed of oil-fired combustion sources utilizing a range of fuels under various operating conditions. The emission factors thus obtained can be used with single source meteorological diffusion equations to estimate ground level concentrations near the sources. Concurrently, ground level concentrations of total and acid sulfates need to be measured under adverse, meteorological conditions near oil-fired emission sources. Additional resources related to measurement aspects are included in that portion of the strategy.

Table 19

SOURCE CHARACTERIZATION FUNDING ($K)

	FY					
	77	78	79	80	81	82
Source Studies	150	250	250	275	250	150

IX. Standardization of Measurement Methodology–

If it is determined that specific sulfates require regulatory action, there will be a need for standardized, routine monitoring instrumentation and measurement methodology. This effort must begin in FY'77 for those specific sulfates which are the focus of this strategy.

2.4.3 Anticipated Results

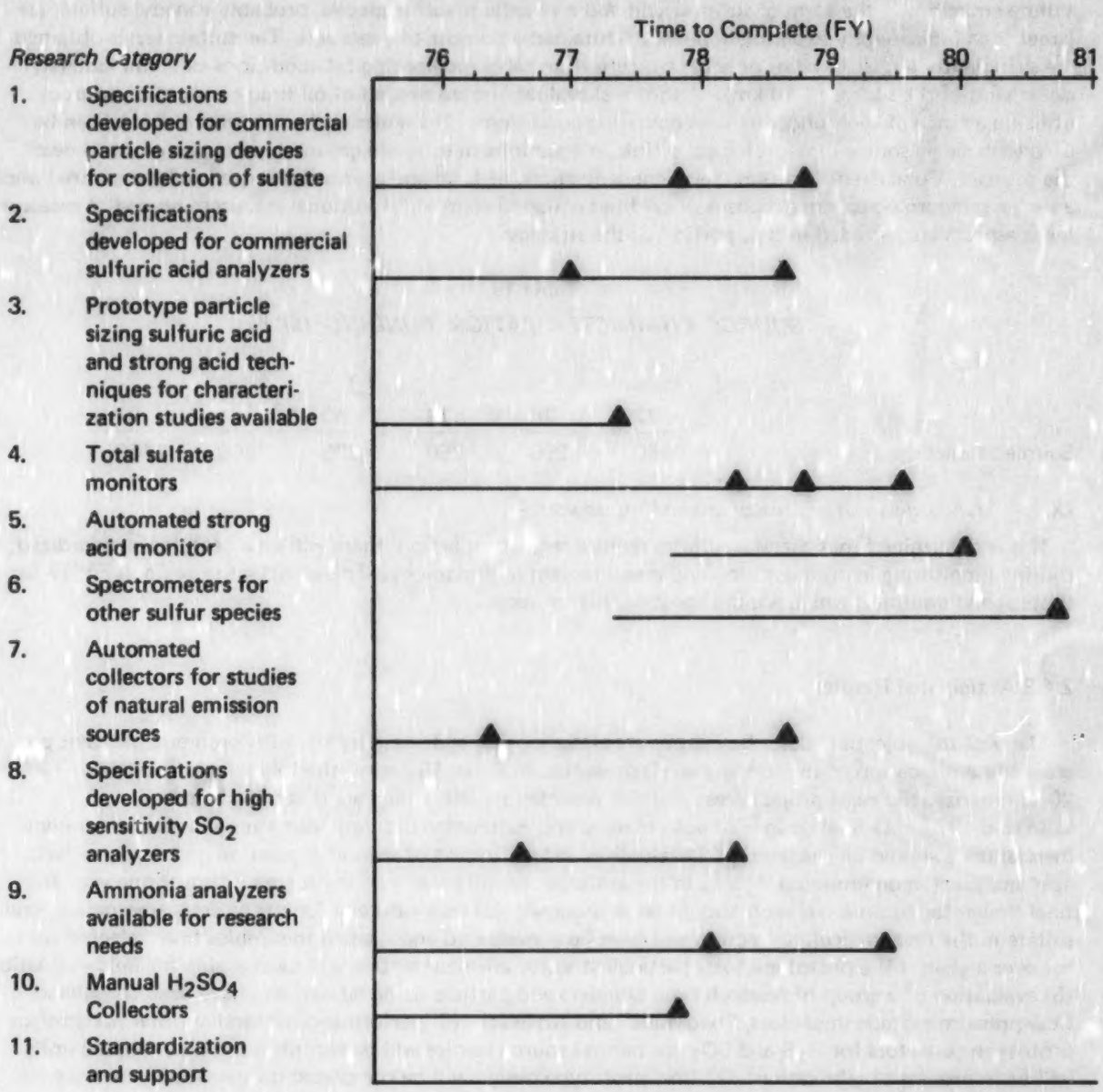
Many of the objectives described above are already being addressed by the EPA program. Current progress and anticipation of the funding levels presented in Table 18 permit the following projections. Table 20 summarizes the eight project areas and the expected results, which are described below:

In mid-1978, (1) final designs of both manual and automated dichotomous samplers needed for commercial units should be available; (2) evaluation and utilization of second generation prototype sulfuric acid analyzers in determining H_2SO_4 in the atmosphere will have been in progress for over one year and final design for commercial units should be in progress; (3) methodology for strong acid, ammonium, and sulfate in the fine particulate fraction will have been evaluated and applied to samples from selected sites for over a year; (4) a prototype total particulate sulfur analyzer system will be available for field evaluatior (5) evaluation of a group of research type samplers and particle sizing devices will have been completed (low pressure cascade impactors, "two mass" and streaker); (6) performance of tandem filter particle/gas prototype collectors for H_2S and SO_2 for natural source studies will be completed and automated units will be in process of fabrication; (7) final prototype design will be completed on the chemiluminescence NH_3 analyzer.

In mid-1979 a number of additional developments could be available: (1) lower cost dichotomous samplers could be commercially available; (2) sulfuric acid analyzers could be commercially available; (3) second generation prototype total particulate sulfur analyzers could be available; (4) high sensitivity SO_2 analyzers (0.1 ppb detection limit) should be commercially available; and (5) ammonia analyzers should be available for routine field use in research programs.

Table 20

MEASUREMENT METHODOLOGY AND INSTRUMENTATION ACCOMPLISHMENT STRATEGY


Time to Complete (FY)
Research Category
76
77
78
79
80
81
1. Specifications developed for commercial particle sizing devices for collection of sulfate
2. Specifications developed for commercial sulfuric acid analyzers
3. Prototype particle sizing sulfuric acid and strong acid techniques for characterization studies available
4. Total sulfate monitors
5. Automated strong acid monitor
6. Spectrometers for other sulfur species
7. Automated collectors for studies of natural emission sources
8. Specifications developed for high sensitivity SO_2 analyzers
9. Ammonia analyzers available for research needs
10. Manual H_2SO_4 Collectors
11. Standardization and support

APPENDIX 1

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